"The Piscian Stars." By Sir NORMAN LOCKYER, K.C.B., F.R.S.

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Introductory.

In the Bakerian Lecture for 1888* I briefly considered the relation of the stars having spectra with predominant carbon absorption (for which I have recently suggested the name *Piscian*†) to the various other types of celestial bodies. Shortly afterwards I began the discussion of the observations which had been made by Dunér in the case of these stars. Those relating to Group II (now named *Antarian*), another group studied by Dunér, were fully dealt with in the Bakerian Lecture, but after all the available information as to the former had been brought together, I found that notwithstanding the admirable data which Dunér had put on record, there were some points on which further information was desirable.

In the Antarian stars we had evidence as to the lines present in company with the various flutings, but in the Piscian stars even the presence or absence of lines was somewhat uncertain.

The publication of this investigation was therefore postponed to see what light could be thrown upon the subject by further observations. At various times, as the work permitted, such observations have been attempted, and the results, so far as they went, did not disturb the classification at which I had already arrived. Still, the information thus gained was less complete than desired.

The photographic work which has quite recently been done on these stars by Dr. McClean and Professor Hale has now furnished the additional information required, and it is therefore unnecessary to delay the publication of the memoir, some ten years old, which in the main points stands as it was written.

Historical Statement.

Secchi was the first to recognise stars with spectra of the type under discussion during his spectroscopic survey made in 1866 and 1867. They constituted his fourth type. All the stars of the group are of small magnitude, and of a deep red colour. He was inclined to believe that a radiation spectrum was in question, but pointed out that there was a relation between the flutings of carbon and the dark bands seen in the spectra of the stars. He says:—" Quelques-unes des raies noires, et les plus importantes, coincident à très-peu près avec celles du troisième type; cependant le spectre, dans son ensemble, se présente

* 'Roy. Soc. Proc.,' vol. 44, p. 26.

† 'Roy. Soc. Proc.' (1899), vol. 65, p. 191.

comme un spectre direct appartenant à un corps gazeux, plutôt que comme un spectre d'absorption. Si on le considère comme un spectre d'absorption on trouve qu'il présente le caractère des composés du carbone, tels qu'on les obtient en produisant une série d'étincelles électriques dans un mélange de vapeur de benzine et d'air atmosphérique et dans l'arc voltaique entres les charbons."*

Secchi also states† that bright lines are occasionally seen in the spectra of stars of this type, and in a diagram of the spectrum of 152 Schjellerup he indicates no less than six bright lines.

Dunér in 1884 catalogued fifty-five stars of this group, and recorded the details of their spectra, so far as he was able to observe them.‡

Referring to Secchi's work, Dunér says:—"Secchi s'est beaucoup occupé de ces spectres, mais il y a de très graves erreurs dans ce qu'il dit sur l'apparence qu'ils offrent et sur leur nature. D'abord il prononce à plusieurs occasions dans sa 'Memoria seconda' et dans son ouvrage 'Le Soleil' que le rouge leur manque presque absolument. Pour ma part, je l'ai trouvé très vif dans tous, seulement un peu pâle en comparaison avec la sous-zone jaune excessivement brillante. Puis Secchi parle des raies *vives* qui termineraient, du côté du violet, les zones brillantes. Mais ni dans la zone verte ni dans la bleu je n'ai vu la moindre chose qui pût expliquer un tel énoncé, et je sais que M. Vogel n'a pas été plus heureux. Quant aux deux raies brillantes que Secchi dit avoir vu dans le jaune, elles se rapportent selon toute probabilité à la sous-zone jaune, laquelle, comme je viens de le dire, est divisée en deux par une bande étroite. Secchi s'est plus tard persuadé, par des mesures, que les deux raies jaunes n'ont pas la même position que celles du sodium; mais il est néanmoins difficile de comprendre comment il a pu croire que cette zone, quarante fois plus large que la distance entre D_1 et D_2, fût les raies du sodium. Au reste il paraît disposé à admettre que tout le spectre est un spectre direct émis par un gaz incandescent. Pour moi, il est tout à fait incontestable que c'est un spectre d'absorption, tout aussi bien que celui des étoiles de la Classe IIIa, et M. Vogel a déjà, il y a quelques années, emis une pareille opinion, et il l'a répétée tout récemment."§

In 1865 Zöllner pointed out that spectra might enable us to determine the relative ages of celestial bodies, and suggested that the yellow and red light of certain stars were indications of a reduction of temperature.‖ There is now no doubt that stars with fluted spectra, whether of Group II (Antarian) or Group VI (Piscian), are cooler than stars like the sun and α Lyræ, which have line spectra. But there is an

* 'Le Soleil,' vol. 2, p. 458.

† *Ibid.*, p. 457.

‡ 'Sur les Étoiles à Spectre de la Troisième Classe,' Stockholm, 1884.

§ *Ibid.*, p. 10.

‖ 'Phot. Unters.,' p. 243.

important difference between the two groups, as I pointed out in the Bakerian Lecture. In the Antarian stars we have to deal with condensing swarms of meteorites in which the temperature is increasing, whereas in the Piscian stars we have an advanced stage in the cooling of masses of meteoritic vapours. In the case of Antarian stars we have mixed radiation and absorption flutings, and I suggested a way in which the stars of the group might be divided into fifteen distinct species, representing successive stages in condensation. We have now to consider a similar classification of the Piscian stars, of which I stated in the Bakerian Lecture (p. 26):—"The species of which it will ultimately be composed are already apparently shadowed forth in the map which accompanies Dunér's volume, and they will evidently be subsequently differentiated by the gradual addition of other absorptions to that of carbon, while at the same time the absorption of carbon gets less and less distinct."

In considering the stars of this group, it is most important to bear in mind that there are indications of carbon absorption in the spectrum of the sun. I first obtained evidence of the existence of carbon vapour in the solar atmosphere in 1874, and in 1878 I communicated a paper to the Royal Society on that subject.* Ångström had already shown that the true carbon *lines* were not reversed in the solar spectrum, but I demonstrated by photographic comparisons that there was a perfect correspondence between the individual members of the brightest part of the fluting in the ultra violet (commencing at λ 3883·55), and a series of fine dark lines in the solar spectrum. I pointed out that this carbon vapour existed in a more complicated molecular condition (as is evidenced by the flutings) than the metallic vapours in the sun's atmosphere.†

There can therefore be no doubt that in the sun carbon absorption is just commencing, and that, as I stated in a former paper,‡ "the indications of carbon will go on increasing in intensity slowly, until a stage is reached when, owing to reduction of temperature of the most effective absorbing layer, the chief absorption will be that of carbon—a stage in which we now find the stars of Class III*b* of Vogel's classification."

* 'Roy. Soc. Proc.,' vol. 27, p. 308.

† *Note* (*added* 1899).—Professor Rowland has since identified a considerable number of faint lines in the solar spectrum, on the more refrangible side of *b*, with the constituents of the green carbon fluting ('Prelim. Table of Solar Spectrum Wave-lengths,' p. 90), and we thus have direct evidence of the presence in the solar spectrum of the band which is perhaps the most characteristic feature of the Piscian stars.

‡ 'Roy. Soc. Proc.,' vol. 43 (1887), p. 155.

General Characteristics of the Spectra.

The main features of the spectra are three broad dark flutings, which fade off to the violet end of the spectrum. These, as is now well known, coincide with the three principal bands in the spectrum of high temperature* carbon.

The wave-lengths of the bands, and Dunér's numbers, are as follows:—

No. of band.	Duner's mean λ.	Vogel's mean λ.†	Hot carbon (Ångström).
6	563·3	563·1	563·3
9	516·3	515·9	516·4
10	472·7	472·9	473·6

The greatest discrepancy is in the case of band 10, and this is easily explained when we consider the variation of the position of the maximum intensity of the band to which I have previously drawn attention.‡ At different temperatures the position of the brightest part of the band changes, and in Ångström's measure of the carbon fluting this was not taken into account.

In addition to these principal bands, Dunér mapped seven secondary bands. In the Bakerian Lecture, I stated that "there is evidence that some of the absorption is produced by substances which remain in the atmosphere during the next stage, that of Group VII (dark bodies). This probability is based upon the fact that some of the bands are apparently coincident with bands in the telluric spectrum as mapped by Brewster, Ångström, Smyth, and others."§

* As in former papers, the term "high temperature," as used here, is only relative, and refers to the spectrum of carbon which is seen in the electric arc, Bunsen burner, or vacuum tube under certain conditions. The spectrum of carbon at a still higher temperature consists of lines.

† 'Potsdam Observations,' No. 14, 1884, p. 31.

‡ 'Roy. Soc. Proc.,' vol. 45 (1889), p. 167.

§ *Note* (*added* 1899).—Although my subdivision of the group into species, made ten years ago, is based in part upon the secondary bands, it is not materially affected by the new information as to the nature of these bands, since, as cooling goes on, low temperature metallic lines would become more prominent relatively, just as we might have expected the secondary bands to become stronger on the supposition that they had the same origin as the telluric bands.

Specific differences in the Spectra.

In considering the question of variations of spectra with temperature in these stars, the importance of taking differences of magnitude into account must not be lost sight of.

A general examination of Dunér's observations indicates that there are two marked differences in the spectra of the different stars. (1) Some of them give secondary bands, whilst in others they are absent. (2) Some of them have longer continuous spectra than others, as indicated by the number of "zones" visible.

If the continuous spectrum extends far enough towards the violet, the three dark flutings of carbon will divide the spectrum into four bright zones. If it does not extend beyond the most refrangible of the flutings (λ473) only three zones will be visible, and the continuous spectrum will appear to end sharply at wave-length 473. In one case it does not extend beyond the fluting at λ517, and then only two zones are visible.

These differences might evidently depend upon differences of magnitude of the stars concerned, but a detailed examination of the observations shows that some of the differences do not depend upon brightness. If we consider the visibility of the secondary bands according to Dunér, we have the following result:—

No. of band.	Wave-length.	Magnitude of stars in which it is seen.	Magnitude of stars in which it is not seen.
1	656·0	5·4—6·2	6·0—9·5
2	621·0	5·4—8·1	6·0—9·5
3	604·8	5·4—8·1	6·0—9·5
4	589·8	5·4—8·5	6·6—9·5
5	576·0	5·4—8·1	7·5—9·5
7	551·0	5·4—6·5	6·0—9·5
8	528·3	5·4—7·0	6·0—9·5

This table shows that the visibility of the secondary bands is not altogether dependent upon the magnitudes of the stars observed. Thus the bands 2 and 3 are seen in some of the stars of the group as low as magnitude 8·1, whilst they are absent from some of the stars of the sixth magnitude.

If we consider the question of the length of the continuous spectrum, we have the following result, the maximum number of zones referring to the longest continuous spectrum:—

Number of zones.	Magnitudes of stars in which they are seen.
4	5·5—8·2
3	6·0—9·5
2	8·0—9·0

Here, again, the visibility of the zones does not depend altogether upon the magnitude. There are stars as bright as the sixth magnitude which only give three zones, whilst some as low as 8·2 give four. Dunér refers to this difference as follows:—

"Puis l'intensité de la lumière des zones brillantes peut varier considérablement chez les étoiles de la même grandeur. Dans les étoiles d'un rouge foncé, la zone ultra-bleue est extrêmement faible en comparaison avec la même zone dans les étoiles rouge jaune; et chez les étoiles faibles, cette zone est tout-à-fait invisible, et même la zone bleue est très difficile à voir si elles sont très rouge."*

Another important difference is the variation in the intensity of the citron band of carbon (band 6) as compared with the other bands. Dunér also refers to this point (p. 10) as follows:—"Mais aussi la bande principale à la longueur d'onde 563 est d'une opacité très variée. Chez certaines étoiles, elle est presque aussi foncée que les deux autres bandes principales; mais dans certains spectres elle est assez faible, et semble, probablement à cause de cela, être beaucoup moins large que les bandes aux longueurs d'onde 516 et 473. Celles-ci, et surtout la première d'entre elles, sont toujours très fortes et très larges, et forment le caractère le plus prononcé de ces spectres." A discussion of the observations shows that this variation is independent of the magnitudes of the stars.

Thus we find that the band is dark in some stars with magnitudes varying from 5·4 to 8·0. It is interesting to note that this band, as I have shown, is also the one most subject to variations in the spectra of comets.†

It thus appears that there are distinct differences in the spectra, quite independent of the difficulties in recording the details.

It will be clear that the stars with the longest spectra, characterised by four "zones," must be placed above those with shorter spectra on the temperature curve. As none of the stars, however, show more than four zones and only one less than three, this alone does not discriminate sufficiently between the different species, and we have therefore to look to the variations in the carbon flutings and secondary bands for finer sub-division.

* 'Sur les Étoiles,' &c., p. 9.

† 'Roy. Soc. Proc.,' vol. 45 (1889), p. 168.

In the last stages of all, before final extinction, the stars will be so feeble that the details of their spectra cannot be recorded; so that the expected phenomena, on following out continuity of changes, cannot be checked by direct observation. The sequence of changes which we should expect to occur would be :—

(1) The gradual darkening of the carbon flutings and subsequent paling as the continuous spectrum becomes weaker.
(2) The gradual fading out of those solar lines which do not persist as low as flame temperature.
(3) The gradual increase in the intensity of absorption lines or bands representative of low temperature.

Taking Dunér's observations as we find them, we arrange the stars in seven species, particulars of which follow :—

Species 1.

Characteristics.—Four zones. Band 6 pale; secondary bands 4 and 5 present, or perhaps 4 without 5.

No. 3, 7 *Schj.*, *Mag.* 7·0 *Rrj.*—Four zones, band 6 weaker than usual; band 4 fairly distinct.

No. 18, 74 *Schj.*, *Mag.* 6·5 *Rrj.*—Four zones; band 6 rather weak; 4 and 5 well seen.

Species 2.

Characteristics—Four zones. Band 6 pale; secondary bands 2, 3, 4, and 5 present.

No. 11, 51 *Schj.*, *Mag.* 6·3 *Rrj.*—Four zones. Band 6 weaker than 9 and 10; 2, 3, 4, and 5 seen.

Species 3.

Characteristics—Four zones. Band 6 pale; secondary bands 1, 2, 3, 4, 5, 7, and 8.

No. 25, 132 *Schj.* (*U Hydræ*), *Mag.* 5·4 (*Var.*) *Rrj.*—Four zones. Band 6 weak; 1, 2, 3, 4, 5, 7, and 8 strongly developed.

No. 26, *D.M.* + 68° 617, *Mag.* 6·2 *Rrj.*—Four zones. Band 6 weaker than 9 and 10; 1, 2, 3 rather weak; 4 and 5 well seen; 7 and 8 seen with difficulty.

No. 55, 19 *Piscium*, *Mag.* 6·2 *Rrj.*—Four zones. Band 6 relatively feeble; 1, 2, 3, 4, 5, 7, and 8 are visible.

Species 4.

Characteristics.—Four zones. Band 6 dark; secondary bands all visible.

No. 29, 152 *Schj., Mag.* 5·5 *Rrj.*—Four zones. Carbon bands wide and dark; secondary bands 3, 4, 5 well seen; 1, 2, 7, and 8 feebly visible.

No. 40, 229 *Schj., Mag.* 6·5 *Rrj.*—Four zones. Carbon bands wide and dark; bands 2, 3, 4, 5, and 8 seen, but weak.

No. 52, 249*a* *Schj., Mag.* 6·2 *Rrj.*—Four zones. Bands 2, 3, 4, 5, 7, and 8 well seen.

Species 5.

Characteristics.—Three zones, with trace of ultra-blue zone. Carbon band dark. All secondary bands visible in the brighter stars. In the fainter stars bands 1, 2, and 3 would probably not be seen, as they are in an obscure part of the spectrum.

No. 6, *D.M.* + 57° 702, *Mag.* 7·9 *Rrj.*—Four zones; ultra-blue excessively weak. Carbon bands wide and dark; 4 and 5 well seen; 7 and 8 possibly visible.

Species 6.

Characteristics.—Three zones. Band 6 dark. These stars will in general be dim, so that the secondary bands will only be well seen in the brighter stars of the species.

No. 1, 3 *Schj., Mag.* 8·2 *Rrrj.*—Three zones; blue very pale. Band 6 wide and dark. Band 4 probably visible.

No. 2, *D.M.* + 34° 56, *Mag.* 8·1 *Rrrj.*—Three zones. Band 4 glimpsed.

No. 7, 27*a* *Schj., Mag.* 6·6 *Rrj.*—Three zones; blue faint. Band 2 probably seen.

No. 8, 41 *Schj., Mag.* 7·0 *Rrj.*—Three zones. Carbon bands wide and dark; bands 4 and 5 seen, and band 8 glimpsed.

No. 13, *S Aurigæ* (*Var.*) *Rrrj.*—Two zones only. Spectrum very weak, but band 6 is dark. Very little detail was observed here, probably on account of the faintness of the spectrum, the star being only magnitude 9·4 at maximum.

No. 15, 64*a* *Schj., Mag.* 7·7 *Rrj.*—Three zones; blue weak. Carbon bands very strong; bands 4 and 5 well seen; 2 and 3 glimpsed.

No. 21, 89 *Schj., Mag.* 7·5 *Rrj.*—Three zones. Band 6 rather dark.

No. 24, 124 *Schj., Mag.* 6·5 *Rrj.*—Three zones. Carbon bands very wide and dark; 4 and 5 well seen.

No. 27, 136 *Schj., Mag.* 6·0 *Rrrj.*—Three zones. Bands 4 and 5 well seen.

No. 28, 145 *Schj., Mag.* 8·1 *Rrj.*—Three zones. Bands 4 and 5 well seen; 2 and 3 possibly present.

No. 30, 155*b* *Schj.*, *Mag.* 7·3 *Rrj.*—Three zones. Carbon bands very dark; bands 4 and 5 well seen; 1, 2, 3 very feebly visible.

No. 33, 202 *Schj.*, *Mag.* 8·5 *Rrrj.*—Three zones. Band 6 dark; ? band 4.

No. 35, *D.M.* + 36° 3168, *Mag.* 8·5 *Rrj.*—Three zones. Carbon bands wide and dark; trace of band 4.

No. 37, 219 *Schj.*, *Mag.* 8·0 *Rrj.*—Three zones. Carbon bands very wide and dark; bands 4 and 5 seen; band 2 present, but very weak.

No. 38, 222 *Schj.*, *Mag.* 9·0 *Rrrj.*—Three zones; blue very weak. Carbon bands strong. No secondary bands were recorded, probably because of the faintness of the spectrum.

No. 39, 222*e* *Schj.*, *Mag.* 7·3 *Rrrj.*—Three zones; blue very weak; 4 and 5 distinctly visible.

No. 41, 228 *Schj.*, *Mag.* 7·0 *Rj.*—Three zones. Bands 2, 3, 4, and 5 visible.

No. 42, *D.M.* + 32° 3522, *Mag.* 8·0 *Rrj.*—Three zones; blue rather bright. Carbon bands very wide and dark; 4 and 5 seen.

No. 45, *D.M.* + 35° 4002, *Mag.* 9·5 *Rrj.*—Three zones. Carbon bands very wide and dark. (The absence of secondary bands probably due to faintness of star.)

No. 49, *V Cygni* (*Var.*) *Rrrj.*—Three zones. Band 6 wide and dark.

No. 51, *S Cephei* (*Var.*) *Rrrj.*—Three zones. Band 6 wide and dark.

No. 53, 251 *Schj.*, *Mag.* 7·8 *Rrrj.*—Three zones. Bands 4 and 5 doubtful.

Species 7.

Characteristics.—Three zones. Band 6 pale.

No. 9, 43 *Schj.*, *Mag.* 8·1 *Rrrj.*—Three zones. Band 9 strong; band 6 pale.

No. 12, 99 *Birm.*, *Mag.* 8·0 *Rrj.*—Three zones. Band 9 very strong; band 6 weak.

No. 16, 72 *Schj.*, *Mag.* 7·4 *Rrj.*—Three zones. Bands 9 and 10 wide and dark; band 6 weaker; possibly bands 4 and 5 are visible.

No. 31, *V Coronæ* (*Var.*) *Rrj.*—Three zones. Band 9 strong; 6 rather weak.

No. 48, *U Cygni* (*Var.*) *Rrrj.*—Three feeble zones. Band 6 weak.

The remaining stars of the group observed by Dunér are not described with sufficient detail to enable them to be included in the foregoing classification.

The variations from one species to another are shown in the accompanying map (p. 136), which also indicates the connection with stars of the group which precedes it, and suggests a later Species 8, not yet identified by observation.

Owing to the difficulties attending the observations, the actual appearances of the secondary bands are not quite so regular as is shown in the map.

The Colours of the Piscian Stars.

The classification arrived at was next tested by reference to the colour phenomena. Dunér employs two methods of indicating the colours of the stars, which he has specially observed—first, by means of initial letters, and second, by means of numbers, such that 10 = blood red. Thus:

Rj = rouge jaune.
Rrj = rouge jaune foncé.
Rrrj = presque rouge absolue.

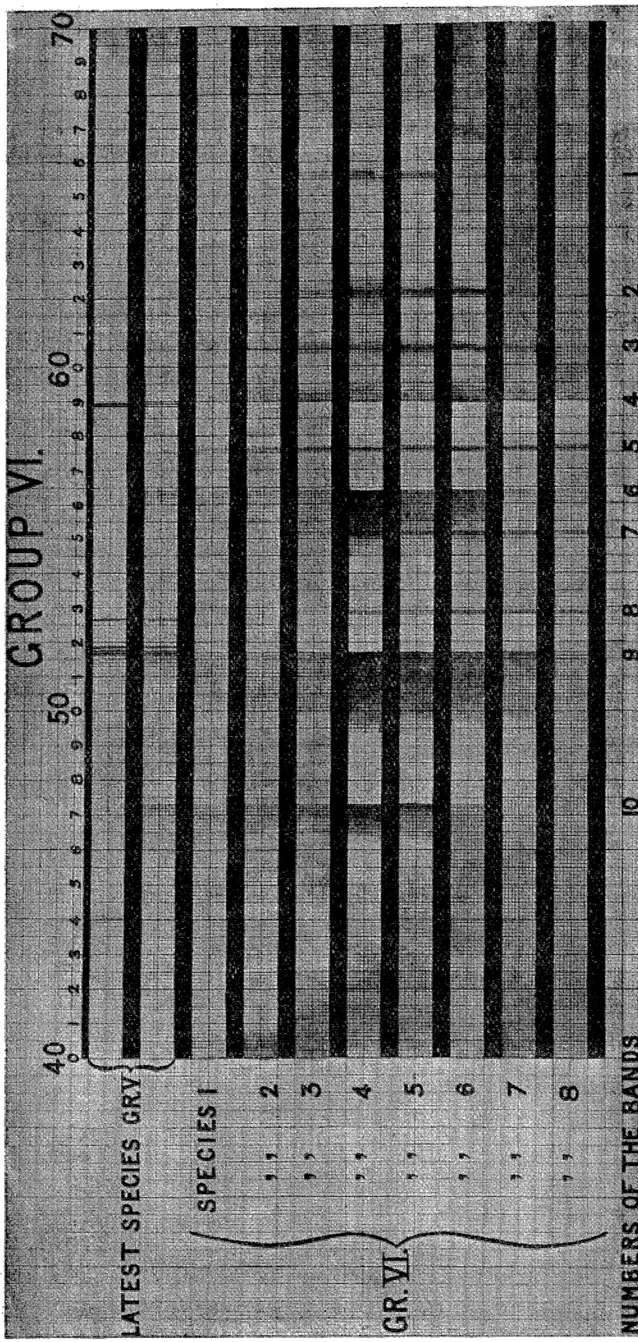
The numbers show a fair agreement with the letters employed, if we omit one Rrj star, which is given the number 9·3. The following table compares the colour numbers corresponding to the initial letters:—

Initial letters.	Range of numbers corresponding.	Mean No.	Remarks.
Rj	..	8·2	One member only.
Rrj	7·8—8·6	8·3	One star, 9·3, omitted.
Rrrj	8·8—9·5	9·04	

If we consider the colour numbers corresponding to the various species into which I have divided the group, we find the average numbers to be as follows:—

Species	1	8·1
	2	8·6
	3	8·2
	4	8·1
	5	8·2
	6	8·8
	7	8·6

On the whole, therefore, considering the difficulty of the observations, there is an increase of redness as we pass successively through



Map showing the Species of Piscian Stars.

successive species, which is exactly what we should expect if these species truly represent the effect of gradual cooling.

Variability of Piscian Stars.

Of the fifty-five stars in Dunér's list, ten exhibit fluctuations in brilliancy.

On the whole the light changes are not so great as in the stars of Group II, and the periods tend to greater length.

As to the cause of variability, the increase of light at maximum may be due, as I suggested in 1890,* to the light added by bodies of a cometary character when they reach periastron, the increase of luminosity being produced by tidal action, as in the case of comets in our own solar system. If there be any truth in this idea, it seems probable that the added light of the comet at maximum, which would give a spectrum consisting of bright carbon flutings, would produce a paling of the carbon absorption flutings.

As in the variables of the Antarian group, which are uncondensed swarms, and where, on the meteoritic hypothesis, the increased light at maximum is produced by the collision of a revolving swarm at periastron, irregularity is a natural consequence of the revolution of more than one secondary body.

ADDENDUM.

Recent Observations.

The Kensington observations were made chiefly during 1894 and 1895, with special reference to the lines involved. The stars selected for observation were 132 Schjellerup, 152 Schjellerup, 115 Schjellerup, and 19 Piscium. The 3-foot reflector was used. In addition to the carbon bands, numerous lines were seen without much difficulty, but only the more prominent ones could be satisfactorily measured. Among the lines recorded in 132 Schj. were $H\beta$, the E line of iron at 5269, and a group of lines near λ 5380. In 115 Schjellerup additional lines were measured near 5005, 5762, and 5429, and the presence of $H\beta$ was again determined by comparison with a hydrogen vacuum tube. In 19 Piscium numerous lines were observed, among them being D and F. No suspicion of bright lines was entertained during these observations. Attempts to photograph the spectra were not sufficiently successful to help matters.

In 1898, Dr. McClean published photographs of the spectra of 19 Piscium and 152 Schjellerup,† showing that these stars have a line spectrum similar to α Tauri, in addition to the well-marked bands

* 'Nature,' vol. 42, pp. 419, 548.

† 'Phil. Trans.,' vol. 191, A, p. 131, plate 14.

of carbon. This was the information wanted, but more recently Professor Hale has published photographs of the spectra of 280 Schj., 273 Schj. (19 Piscium), 132 Schj. (U Hydræ), and 152 Schj., taken with the aid of the Yerke's telescope at Chicago, and showing a wealth of fine detail.* The dark line spectrum is very marked, and the details of the carbon bands themselves are clearly revealed. Besides these, there are certain bright places in the spectrum which Professor Hale has been led to believe are true bright lines, and he mentions that Professor Keeler has arrived at the same conclusion as a result of his observations with the Lick refractor.

Dunér appears to have continued his observations of this group of stars after his removal from Lund to Upsala, and he states that with the Upsala refractor he was able to see more detail, and could detect without difficulty bright lines in the spectra of various stars of the group.†

The Question of Bright Lines.

As I have already pointed out, Professors Hale, Keeler, and Dunér consider that there are bright lines in some of these spectra, but I must confess that the published photographs do not convince me upon this point. In the plate which accompanies Professor Hale's paper of April, 1899,‡ the spectra of four stars are shown, namely, 280 Schj., 273 Schj., 132 Schj., and 152 Schj. A study of these photographs shows that the supposed bright lines are involved in the carbon absorption bands in the yellow green, and occur where there is reduced absorption, on the less refrangible sides of the dark flutings.

This at once led me to suppose that they could not be real bright lines, but simply places in the continuous spectrum where there is least absorption. These supposed bright lines are most marked in 152 Schj., and there is no suggestion of them in 280 Schj., while I think few would be disposed to suggest their presence in 273 Schj. and 132 Schj. without having 152 Schj. as a guide. Nevertheless, in these intermediate stars there are certainly bright *places* corresponding in position with the "bright lines" in 152 Schj., the principal one being at λ 5592. So far as appearances go, the greater apparent intensity of the bright line in 152 Schj. appears to be due to the introduction of a strong absorption line on the less refrangible side.

In another paper§ Professor Hale reproduces photographs of 152 Schj. in which the contrast has been increased by photographic means, so that the whole spectrum appears to consist of bright lines, rather than dark ones.

* 'Astrophys. Journ.,' vol. 8, pp. 238–9; vol. 9, p. 271; vol. 10, p. 110.

† 'Astrophys. Journ.,' vol. 9, p. 121.

‡ 'Astrophys. Journ.,' vol. 9, p. 271.

§ 'Astrophys. Journ.,' vol. 10, August, 1899, p. 108.

In favour of the real existence of bright lines, Professor Hale points out that the contrast between the line and the continuous spectrum increased rather than diminished when dispersion was increased, and that there was no decrease in contrast as the slit was widened. The question, however, is so complicated by the presence of the carbon fluting and other absorptions, that I shall not follow Professor Hale in his definite conclusions as to bright lines upon these grounds.

Before we can admit the certain presence of bright lines in 152 Schj., we must consider whether similar appearances occur in other stars where bright lines have not been previously suspected. As a matter of fact, in the photographic spectra of α Tauri, β Andromedæ, and α Orionis, which I published in 1893,* the spectra might, so far as mere appearance goes, be regarded as containing both bright and dark lines, some of the bright spaces between obvious dark lines being very conspicuous; the same remark applies in a less degree to the spectrum of Arcturus which I published at the same time. But we find a complete explanation of these spectra if we regard them as consisting of dark lines, whereas if we take the bright spaces we cannot match them at all. We do not hesitate in these cases to treat the spectra as consisting of dark lines only, the apparent bright lines being simply spaces between dark ones. I find that practically in all dark line spectra where the lines are from some cause or other thick, the intervals between them are apt to appear as bright lines, and this brightness can readily be intensified by purely photographic processes.

I have accordingly thought it unnecessary to modify the division into species on account of the supposed presence in some of them of bright lines. If the presence of bright lines be eventually established, may they not indicate that we are observing the effects of volcanic gases floating over a "photosphere" which has attained the consistency of lava?

Bearing on the Meteoritic Hypothesis.

The photographs taken by McClean and Hale have now sufficiently shown that there is much in common between the line spectra of the Antarian and Piscian stars. This indicates that there is a practical equality of mean temperature in the reversing layers of the two groups, but we find a very great difference in the conditions as to carbon; while carbon is undoubtedly absorbing in the Piscian stars, it is certainly not absorbing in the Antarian, and there is in fact strong evidence that it is radiating.†

We cannot imagine different kinds of stars of the same temperature as representing the same stage in any evolutionary scheme, so that the

* 'Phil. Trans.,' A, vol. 186 (1893), plate 23.

† 'Roy. Soc. Proc.,' vol. 44 (1888), p. 52; 'Phil. Trans.,' A, vol. 186 (1893), p. 704.

separation of the two groups which I suggested in 1887 is fully justified by the recent work to which I have referred. By putting the two groups on the same level of temperature, but on opposite sides of the temperature curve, as in the evolutionary order forming part of the meteoritic hypothesis, the differences are fully explained.

It will be seen that this work carries us a step beyond that with which I have recently been engaged in connection with the hotter stars.

General Conclusions.

(1) The undoubted presence of dark carbon flutings in the solar spectrum, including that near *b*, and of solar lines in the Piscian stars, indicates that the Piscian stars are next in order of development to the Arcturian stars.

(2) The stars observed by Dunér may be divided into seven species, beginning with the hottest and ending with the coolest stars.

(3) The reported presence of bright lines in the Piscian stars must be received with caution, as similar evidence of bright lines might be adduced in the case of other classes of stars in which the spectrum is fully explained by dark lines alone.

(4) The redness of the stars increases as we pass from the earlier to the later species of the group.

(5) The variability in this group is less marked than in the Antarian stars, and may perhaps be accounted for by the revolution of secondary bodies of the nature of comets round the stars themselves.

(6) The place on the temperature curve assigned to these stars on the meteoritic hypothesis is fully confirmed by the more detailed inquiry, and the hypothesis is thereby strengthened.

I am indebted to Mr. Fowler for assistance in the determination of the species and the construction of the map ten years ago, and for additional assistance in discussing the recent work. I have also to express my thanks to Mr. Shackleton for a detailed examination of the recent photographs.

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(1) *Introductory.*—In a memoir recently presented to the Royal Society, I have endeavoured to emphasise the importance of distin-

Map showing the Species of Piscian Stars.